Physics Potential of Solar Neutrino Experiments

A.B. Balantekin[a][*], H. Yüksel[a][†]

[a]University of Wisconsin, Department of Physics, Madison, WI 53706 USA

We discuss the physics potential of the solar neutrino experiments i) To explore the parameter space of neutrino mass and mixings; ii) To probe the physics of the Sun; iii) To explore nuclear physics of the neutrino-target interactions. Examples are given for these three classes.

Recently announced results from the Sudbury Neutrino Observatory (SNO) [1] and KamLAND [2] experiments indicate that neutrino physics is moving from the discovery stage to the precision measurements stage. (For recent reviews see e. g. [3,4]). A combined analysis of the data from these experiments as well as data from other solar neutrino experiments (Super-Kamiokande [SK] [5], Chlorine [6], and Gallium [7,8,9]), place severe constraints on the neutrino parameters, especially mixing between first and second generations [10,11,12]. As an example the neutrino parameter space obtained from the global analysis of all available solar neutrino plus the KamLAND data is shown in Fig. 1 [12].

The aim of this short contribution is to re-emphasize that, in principle, high-precision solar-neutrino data have potential beyond exploring neutrino parameter space. Here we consider two other applications to solar physics and to nuclear physics of the neutrino-target interactions.

Some time ago it was pointed out that solar neutrino data can be inverted to extract information about the density scale height [13] in a similar way the helioseismological information is inverted to obtain the sound-speed profile throughout the Sun. Even though the precision of the data has not yet reached to a point where such an inversion is possible, it is currently possible to obtain rather tight limits on *fluctuations* of the solar density. To do so one assumes [14] that the electron density N_e fluctuates around the value, $\langle N_e \rangle$,
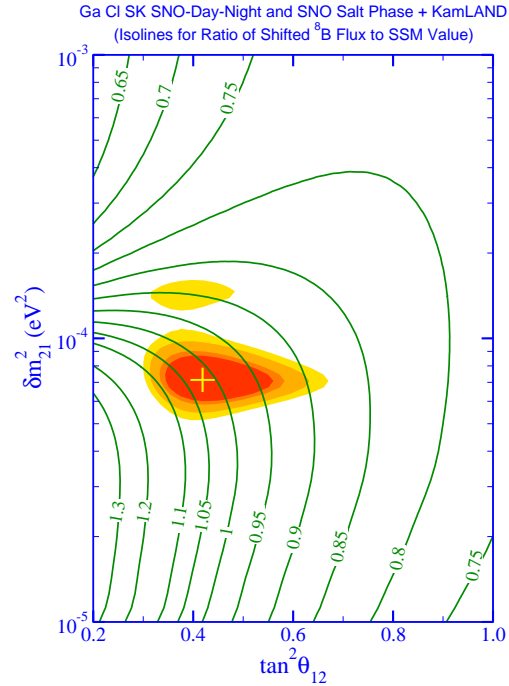

Figure 1. Allowed confidence levels from the joint analysis of all available solar neutrino data (chlorine, average gallium, SNO and SK spectra and SNO salt phase) and KamLAND reactor data The isolines are the ratio of the shifted ^{8}B flux to the SSM value. At best fit (marked by a cross) the value of this ratio is 1.02 (from Ref. [12]).

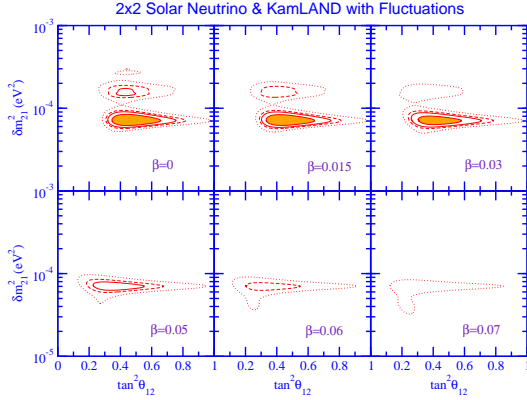[*]baha@nucth.physics.wisc.edu
[†]yuksel@nucth.physics.wisc.edu

Figure 2. Allowed regions of the neutrino parameter space with solar-density fluctuations when the data from the solar neutrino and KamLAND experiments are used. The SSM density profile of Ref. [15] and the correlation length of 10 km are used. The case with no fluctuations ($\beta = 0$) are compared with results obtained with the indicated fractional fluctuation. The shaded area is the 70 % confidence level region. 90 % (solid line), 95 % (dashed line), and 99 % (dotted line) confidence levels are also shown (From Ref. [16]).

predicted by the Standard Solar Model (SSM) [15]

$$N_e(r) = (1 + \beta F(r))\langle N_e(r)\rangle, \tag{1}$$

and that the fluctuation $F(r)$ takes the form of white-noise. The neutrino parameter space for various values of the parameter β was calculated in Ref. [16] and is shown in Figure 2. These results, in agreement with the calculations of other authors [17,18], show that the neutrino data constrains solar density fluctuations to be less than $\beta = 0.05$ at the 70 % confidence level. The best fit to the combined solar neutrino and KamLAND data is given by $\beta = 0$ (exact SSM).

In the effective field theory approach to nuclear interactions, nonlocal interactions at short distances are represented by effective local interactions in a derivative expansion. Since the effect of a given operator on low-energy physics is inversely proportional to its dimension, an effective
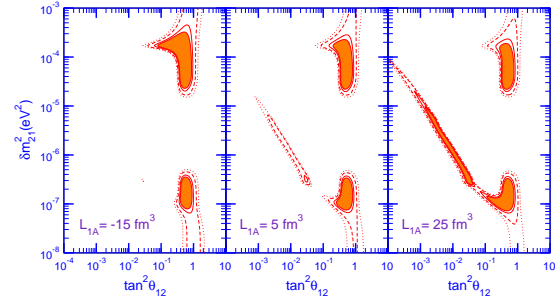

Figure 3. The change in the allowed region of the neutrino parameter space using solar neutrino data measured at SNO as the value of L_{1A} changes. The shaded areas are the 90 % confidence level region. 95 % (solid line), 99 % (log-dashed line), and 99.73 % (dotted-line) confidence levels are also shown (From Ref. [21]).

theory valid at low energies can be written down by retaining operators up to a given dimension. It turns out that one needs to introduce a single coefficient, commonly called L_{1A}, to parameterize the unknown isovector axial two-body current which dominates the uncertainties of all neutrino-deuteron interactions [19]. Chen, Heeger, and Robertson, using the Sudbury Neutrino Observatory (SNO) and SuperKamiokande (SK) charged-current, neutral current, and elastic scattering rate data, found [20] $L_{1A} = 4.0 \pm 6.3\,\text{fm}^3$. In order to obtain this result they wrote the observed rate in terms of an averaged effective cross section and a suitably defined response function. One can explore the phenomenology associated with the variation of L_{1A}. For example the variation of the neutrino parameter space, which fits the SNO data, as L_{1A} changes was calculated in [21] and is shown in Figure 3. In Ref. [21] the most conservative fit value with fewest assumptions is found to be $L_{1A} = 4.5^{+18}_{-12}\,\text{fm}^3$. It was also shown that the contribution of the uncertainty of L_{1A} to the analysis and interpretation of the solar neutrino data measured at the Sudbury Neutrino Observatory is significantly less than the uncertainty coming from the lack of having a better knowl-

edge of θ_{13}, the mixing angle between first and third generations.

In conclusion we would like to reiterate that the utility of the solar neutrino and related reactor and long-baseline neutrino experiments goes well beyond that of exploring neutrino parameter space. In this short note we briefly discussed only two of such applications out of a much longer list.

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